THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

# Capacity Pooling in Healthcare Systems

## Application of Portfolio Theory to Capacity Management

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Department of Technology Management and Economics
CHALMERS UNIVERSITY OF TECHNOLOGY
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# Abstract

Healthcare systems are facing a continuously increasing demand for care while healthcare providers express a need for additional capacity. However, increased capacity in healthcare systems will not be a sufficient option in the near future, and previous research has found a need to improve healthcare capacity planning and management. Capacity planning is aggravated with the presence of variations in a system, and proactive and reactive tools for short-term flexibility in capacity management can be applied to cope with variations in both capacity and demand. One such proactive tool is a capacity pool, which is a general capacity that can be allocated to parts of the system where the temporary need for resources is unusually high.

The purpose of this thesis is to develop principles and guidelines for a capacity pooling system in the healthcare sector. A theoretical framework that describes the limiting effects of aggregated variations is modern portfolio theory, first originated in the finance sector. Portfolio theory is in this thesis used to demonstrate the effects on resource utilization when capacity is organized into capacity pools. The study object is Region Västra Götaland, a healthcare provider and multihospital system in Sweden. The approach of the research project has been systematic, using a mixed-methods approach with predominantly quantitative studies. An interview study, a questionnaire study and a literature review have been conducted to answer the research questions, resulting in three papers.

This research project has resulted in several findings which can be useful for healthcare managers when designing and implementing capacity pools. The results include examples on how portfolio theory could be used to design capacity pools, knowledge on the use of proactive and reactive tools for short-term flexibility solutions in healthcare capacity management, and perceived barriers to a capacity pooling approach in healthcare systems. Furthermore, the findings in the three papers contribute to the existing research in several ways. For example, previous studies have requested research with a holistic approach on capacity management in healthcare systems and have highlighted the importance of researching temporary capacity changes in healthcare. The research in this thesis has through a mixed-method systematic approach focused on capacity management in a multihospital system consisting of several healthcare providers, including all types of healthcare personnel, and has provided knowledge on the use of flexibility tools for managing variations in capacity and demand.

**Keywords:** healthcare management, capacity pools, capacity management, portfolio theory, volume flexibility

# List of appended papers

**Paper 1:**

Fagefors, C. and Lantz, B. 2021. Application of Portfolio Theory to Healthcare Capacity Management. *International Journal of Environmental Research and Public Health* 18, 659.

An earlier version of the paper was presented at the PLAN conference in October 2020.

**Paper 2:**

Fagefors, C., Lantz, B. and Rosén, P. 2020. Creating Short-Term Volume Flexibility in Healthcare Capacity Management. *International Journal of Environmental Research and Public Health* 17, 8514.

An earlier version of the paper was presented at the PLAN conference in October 2019.

**Paper 3:**

Fagefors, C., Lantz, B., Rosén, P. and Siljemyr, L. 2021. Capacity Pooling in Healthcare Systems – Results from a Mixed-Methods Study. The paper has been submitted to a respected journal and is awaiting the review process.

An earlier version of the paper was presented at the NOFOMA conference in June 2019.

# Acknowledgements

After graduating my engineering studies at Chalmers University of Technology in 2015, I started working with healthcare logistics and operational development at Sahlgrenska University Hospital. I truly love my job, but have always longed for continuing the academic path, which is why I did not hesitate when I was offered a position as an industrial PhD student. Since 2019, I have been working half-time at Sahlgrenska and spent half-time with my doctoral studies at Chalmers, which according to me is the perfect combination.  Experience and knowledge that I have gathered during the years in the healthcare sector have been useful in my PhD process, and vice versa.

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# 1 Introduction

*In this introductory section, a background to the research project is provided, followed by a description of the research setting and the purpose of the study. Finally, the limitations of the research are defined, and the outline of the thesis is described.*

## 1.1 Background

Healthcare systems are facing a continuously increasing demand for care while capacity is lacking (European Commission, 2018; United Nations, 2019; Swedish Association of Local Authorities and Regions, 2021). The “potential support ratio”, hence the ratio between the number of people in working age and the number of people over 65 years old, is decreasing around the world (United Nations, 2019). The demographical change in Sweden is forecasted to an increase of the population over 80 years old by almost 50 % until 2029, while the number of people in working age will increase with approximately 5 % during the same period of time (Swedish Association of Local Authorities and Regions, 2020). An increasing elderly population will lead to growing consumer demands of public services in general, with challenges on healthcare delivery in particular (Swedish Association of Local Authorities and Regions, 2020).

Low accessibility to healthcare has been an issue for several decades in Sweden (The Health and Social Care Inspectorate, 2021; Väntetider.se, 2021; Swedish Association of Local Authorities and Regions, 2021). According to international comparisons, Swedish healthcare systems produce high quality care, but suffers low productivity and unacceptably long waiting times to both primary and specialized care (Swedish Association of Local Authorities and Regions, 2018; Swedish Agency for Health and Care Services Analysis, 2021; Väntetider.se, 2021; The Health and Social Care Inspectorate, 2021). According to Swedish Association of Local Authorities and Regions (2019), the productivity in the healthcare sector has decreased the past years. The number of employees in the Swedish healthcare sector is historically high, and although more resources have been allocated to healthcare organizations, an equivalent increase of the healthcare production has not been observed (The National Board of Health and Welfare, 2020; Väntetider.se, 2021). Healthcare providers express a need for an increased amount of capacity (The National Board of Health and Welfare, 2020), but even though additional resources are allocated to the healthcare sector, the accessibility does not improve sufficiently. Hence, it seems that an increased amount of capacity in healthcare systems will not be a sufficient option to solve the experienced resource deficit in the near future (Walley et al., 2006). Therefore, there is a need to improve healthcare capacity planning and management in order for healthcare systems to be organized more efficiently (Walley et al., 2006; Keskinocak and Savva, 2020).

The recent covid-19 pandemic has forced healthcare providers to suspend a large amount of non-acute care, which has further aggravated the accessibility issues in healthcare systems. Sweden suffered a 17

% reduction of performed surgeries during 2020 compared to 2019 (Sverigesradio.se, 2021), and the number of patients that have been waiting for surgery for less than three months[1] has decreased from 76 % in November 2019 to 53 % in June 2021 (Väntetider.se, 2021). The postponed healthcare will require several years of dedicated work before queues are restored to original levels, government officials argue (GP.se, 2020), while healthcare professionals are fatigued and have been working more overtime hours than ever (SVT.se, 2020). An already strained healthcare system now faces vast challenges in order to solve the accessibility issues, and a change is therefore required in how capacity is managed in healthcare systems.

## 1.2 Research setting

Capacity planning can be performed on either a strategic, tactical, or operational level, where the latter is concerned with short-term allocation of resources (Slack et al., 2010). In this thesis, short-term is considered the time-period where the system's quantity of capacity is fixed, while in the long-term, the system's capacity is a variable factor. The system is defined based on the time horizon: with a short-term timeframe, the system could be for example an isolated unit, and with a long-term perspective, the system could be one or several organizations. Capacity planning is aggravated with the presence of variations in a system, particularly when capacity and demand must be efficiently matched, and variations occur in both entities (ibid.). This becomes prominent in the service sector, where the simultaneous production and consumption of the service provided requires complete alignment between capacity and demand (Johnston and Clark, 2009). The variations put pressure on the capacity planning process, and a shortage of resources often enforces short-term tools to be applied to solve unexpected situations (Jack and Powers, 2004).

In order to cope with variations in a system, proactive and reactive tools for short-term flexibility in capacity management can be applied. Proactive tools on an operational level are for example the use of over-capacity, which enable temporary increases in demand to be managed, but can be both expensive, inefficient and unfeasible to apply in a system with scarce resources (Jack and Powers, 2006; Slack et al., 2010). On the other hand, reactive tools include for example the use of overtime to cope with unforeseen variations (ibid.), which in the long-term can lead to negative impact on work satisfaction and employee turnover (Sebastiano et al., 2017). Applying solely proactive or reactive measures is inefficient and associated with long-term negative consequences for the organization (Slack et al., 2010; Qin et al., 2015; Sebastiano et al., 2017). Reactive tools can be efficient in an hourly to daily perspective, when resources are required immediately, while proactive tools can be used to manage capacity required the next upcoming days or weeks. A robust system that allows variations must be designed, where a

[1] The statutory time frame for guaranteed care in Sweden, from first visit to surgery

hybrid flexibility solution of proactive and reactive tools combined must be used for short-term flexibility in capacity management to obtain an efficient capacity utilization.

Scarce capacity in healthcare organizations can result in a lacking patient safety or potentially have fatal consequences, why the ability to align capacity and demand is crucial (Petros, 2014; Kumar et al., 2018). In healthcare systems, where a complex network of facilities, equipment and trained workforce must be coordinated, variations in both capacity and demand are even further aggravating (Powers and Jack, 2008). The impact of variations in healthcare systems must be understood, and common sources of variation in healthcare capacity is for example short-term leaves and vacancies, while short-term variation in demand usually is due to patient arrival rate and length of stay (e.g., Walley, 2007; Wright and Bretthauer, 2010; Svalund et al., 2018). Most variation is not caused by unplanned demand, but by the healthcare system itself (Walley et al., 2006). Capacity planning in Swedish healthcare contexts is often performed on a decentralized level in the organization. If a unit during a period of time experiences scarce capacity due to random variation, reactive measures such as the use of overtime or queueing patients are often applied (Jack and Powers, 2004; Jack and Powers, 2009; Wright and Bretthauer, 2010). These reactive tools are often momentarily effective but will in the long-term be both costly and have a negative impact on work environment and quality of care (Jack and Powers, 2004; Jack and Powers, 2009; Wright and Bretthauer, 2010). With decentralized planning, resources can simultaneously be experienced as sufficient at another unit, and the total capacity on an aggregated organizational level can therefore be considered as adequate, while decentralized levels still must apply the use of short-term measures to meet the fluctuations in capacity and demand. A shift towards an increased use of proactive tools for short-term flexibility in healthcare capacity management is therefore required.

There are several examples of proactive tools for short-term flexibility in capacity management, such as over-capacity, cross-trained personnel that can move across units, and external staffing agencies. Although these tools can be used to manage short-term variations in healthcare capacity and demand, they are also associated with high costs, and is therefore not a sufficient option to extensively use in a healthcare system with limited resources (Olhager, 1993; Slack et al., 2010; Roach et al., 2011). A more cost-efficient proactive tool for short-term flexibility management is an internal capacity pool (Kuntz et al., 2015). A capacity pool is a general capacity that can be allocated to parts of the system where the temporary need for resources is unusually high (Vanberkel et al., 2012; Hopp and Lovejoy, 2013; Kuntz et al., 2015). It is a well-known method used in both manufacturing companies and service industries to enable flexibility in capacity management (Kalleberg, 2001; Cagliano et al., 2014; Qin et al., 2015). Capacity pools provide the prerequisites for a total higher capacity utilization and can enable better work environment and is therefore a suitable alternative to inefficient and costly reactive short-term volume flexibility tools (Noon et al., 2003; Hultberg, 2007: Mahar et al., 2011; Kuntz et al., 2015). For example, Lu and Lu (2017) argue that capacity pools can be efficiently used to reduce excessive overtime. There are several theoretical advantages with a capacity pooling approach (Cattani and Schmidt, 2005; Ata and Van Mieghem, 2009; Vanberkel et al., 2012; Hopp and Lovejoy, 2013):

- Centralizing capacity and thereby aggregating several sources of variation can, sometimes drastically, reduce the effect of variations, and therefore reduce the need for and cost of safety capacity without impacting the service level. The effect of variations on an aggregated level is described in modern portfolio theory (Markowitz, 1952). For example, a department consisting of several hospital wards with individual safety capacities will require a higher total number of personnel than if safety capacity was aggregated to a departmental level. This example is further described in section *2.4. Example of portfolio theory applied in a capacity pooling system*.
- When one single queue to all servers is formed in a queueing system instead for individual queues to different servers, the average waiting times can be reduced, which is further explained in queueing theory (see e.g., Slack et al., 2010). For example, if two physicians have individual waiting lists, and one of the physicians complete its waiting list before the other, the result will be that patients queueing to the second physician will experience longer waiting times and the overall capacity utilization will decrease.
- A higher capacity utilization can be achieved on an aggregated level if different types of capacity are scarce in different parts of the system simultaneously. For example, if one specialized healthcare department requires physicians, while a similar specialized healthcare department at another hospital requires nurses, the capacity at each department is experienced as insufficient if staffed individually. However, the overall capacity could be adequate if the resource planning is centralized.

There is a need for further research on short-term capacity change, with a holistic approach on resource-allocation decisions, in healthcare systems (Leeftink et al., 2020; Keskinocak and Savva, 2020). Particularly, there is limited available research on the practical potential of implementing capacity pools in a healthcare context, and the available literature is almost exclusively anecdotal and focused on pools of nurses (e.g., Rudy and Sions, 2003; Linzer et al., 2011; Bates, 2013; Lebanik and Britt, 2015). There is a lack of systematic research that supports the implementation of capacity pools in a healthcare context, for example on how pools can be organized, their impact on capacity utilization and what benefits and barriers that can be expected (Smith-Daniels et al., 1988; Cattani and Schmidt, 2005; Dziuba-Ellis, 2006; Mahar et al., 2011; Mazurenko et al., 2015). Hence, there is a need to create scientifically based guidelines on how capacity pools should be designed in order to increase capacity utilization of available resources. The guidelines should include for example:

- How the optimal numbers of units allocated to the same capacity pool could be determined
- How the size of the capacity pools could be dimensioned given a required service level
- Which specific categories of workforce or types of units that can be pooled

- At what level in the healthcare system the pools (safety capacity) could be located

## 1.3 Purpose

The purpose of this thesis is to develop principles and guidelines for a capacity pooling system in the healthcare sector.

## 1.4 Limitations

There are several examples in the literature of different types of capacity pooling configurations; the pooling of patients, such as patient queues in emergency departments (see e.g., Song et al., 2015), the pooling of equipment, such as patient care beds at hospital wards (see e.g., Best et al., 2015), and the pooling of capacity, such as staff (see e.g., Vanberkel et al., 2012; Hopp & Lovejoy, 2013; Kuntz et al., 2015). This research project will be limited to focus only on staff pools, since the capacity issues in healthcare systems to a large extent is due to a lack of personnel.

Furthermore, this research is focused on short-term variations in healthcare capacity and demand, and therefore short-term flexibility in healthcare capacity management during normal circumstances. This means that periods where the system is put under shock or great pressure (such as pandemics) is not in focus of the research project, although there are lessons to be learned from for example the capacity allocation during the covid-19-pandemic.

## 1.5 Outline of the thesis

The thesis is outlined as follows; chapter 2 will present the literature review and research questions of the project. Chapter 3 will provide the research methodology, with a further description of the study object and research design, followed by an assessment of the research quality. Chapter 4 will summarize the appended papers in this thesis, followed by a discussion in chapter 5. Finally, this licentiate thesis is concluded in chapter 6, whereafter potential areas for future research is presented.

# 2 Literature review and research questions

*In this chapter, the theoretical framework used in the research project is presented, followed by an elaboration of the research questions.*

The purpose of this thesis is to develop principles and guidelines for a capacity pooling system in the healthcare sector. As described in the introduction, healthcare systems are characterized by variations in both patient demand and available resources, which aggravates capacity planning and can result in inefficient resource utilization. The use of capacity pools is a possible solution to this challenge, which is a system where several sources of variations are aggregated (Vanberkel et al., 2012; Hopp and Lovejoy, 2013; Kuntz et al., 2015). In the field of supply chain management and logistics, similar means to manage variations can be found, such as the use of central warehouses and centralization of inventory. One of the benefits with such solutions is that when safety stocks in several warehouses are aggregated to a central warehouse, the overall safety stock can be reduced since the effect of varying demand will decrease (Slack et al., 2010). A theoretical framework that describes the limiting effects of aggregated variations is modern portfolio theory (MPT), first originated in the finance sector (Markovitz, 1952; Francis and Kim, 2013). In order to fulfill the purpose, modern portfolio theory will therefore be used to describe the effects on resource utilization when capacity is organized into capacity pools.

## 2.1 Modern portfolio theory

Modern portfolio theory, hereafter referred to as portfolio theory, is a mathematical framework for selecting profitable portfolios of financial assets through the comprehensive analysis of risk-return trade-offs of a portfolio (Markowitz, 1952; Francis and Kim, 2013). The theory was developed and first published by Harry Markowitz in 1952, at the age of 25, for which he later was rewarded the 1990 Alfred Nobel Memorial Prize in Economic Sciences (Markowitz, 1952; nobelprize.org, 1990). Markowitz's contribution to past financial investment principles was a theory that described the importance of diversification and the effect on portfolios when individual assets' risks are correlated (Markowitz, 1999; Francis and Kim, 2013). The theory advocated to "not put all your eggs in one basket" and urged a shift from the focus on singular assets' risk and return to a comprehensive take on a portfolio as a sum of all individual assets (Markowitz, 1999). The idea behind portfolio theory is that when several sources of variation are aggregated, the effect of the variation will decrease (Markowitz, 1952; Terwiesch et al, 2011; Francis and Kim, 2013). This can be shown through a simple mathematical framework called the mean-variance analysis, which will be further described below.

### 2.1.1 The mean-variance analysis

The expected return of a portfolio can be described as:

$$E(R_p) = \sum_i w_i E(R_i)$$

where $E(R_p)$ is the expected return of the portfolio, $w_i$ is the weighting of asset $i$ and $E(R_i)$ is the expected return of asset $i$. The return variance of the portfolio can thereby be described as:

$$\sigma_p^2 = \sum_i w_i^2 \sigma_i^2 + \sum_i \sum_{j \neq i} w_i w_j \sigma_i \sigma_j \rho_{ij}$$

where $\sigma_p^2$ is the return variance of the portfolio and $\rho_{ij}$ is the correlation coefficient between asset $i$ and asset $j$. The risk of the portfolio is equal to the standard deviation, and can therefore be described as:

$$\sigma_p = \sqrt{\sigma_p^2}$$

where $\sigma_p$ is the standard deviation (risk) of the portfolio. In a simple example, with a two-asset portfolio consisting of assets $A$ and $B$, the return variance of that portfolio can be described as:

$$\sigma_p^2 = w_A^2 \sigma_A^2 + w_B^2 \sigma_B^2 + 2 w_A w_B \sigma_A \sigma_B \rho_{AB}$$

In this simple example it can be concluded that, even with a perfectly positive correlation coefficient between asset $A$ and asset $B$ ($\rho_{AB} = 1$), the risk of the overall portfolio can never be higher than the sum of the risk of each individual asset. However, with a lower correlation coefficient ($\rho_{AB} < 1$), the risk of the overall portfolio will be less than the sum of the risk of each individual asset. The combination of two assets $i$ and $j$ that is not perfectly correlated (correlation coefficient $-1 \leq \rho_{ij} < 1$) is referred to as diversification (Markowitz, 1952; Francis and Kim, 2013).

### 2.1.2 Diversification

The standard deviation (risk) of a portfolio of assets can be reduced by combining assets with correlation coefficients less than one, hence applying diversification (Markowitz, 1952). Mainly two types of risks are considered in MPT: unsystematic and systematic risks (Francis and Kim, 2013; Koumou, 2020). Through diversification the expected return of a portfolio can be maintained with a decreased unsystematic risk, meaning that the risks associated with individual stocks can be reduced (Francis and Kim, 2013; Koumou, 2020). For example, a diversified portfolio can be assembled through combining assets from different industries. The systematic risk, hence the risk associated with the entire market or market segment, is on the other hand impossible to completely avoid and therefore remains undiversified (Francis and Kim, 2013).

Figure 1 below visualizes the effect of diversification on unsystematic risks (from Lee et al., 2010, p. 80). It shows that the standard deviation of a portfolio will be reduced when extra assets (stocks) are added to the portfolio. The figure also shows that there is a systematic risk in terms of market risk that will not be affected by diversification and can therefore be considered the lowest amount of risk that an investor can and should accept.

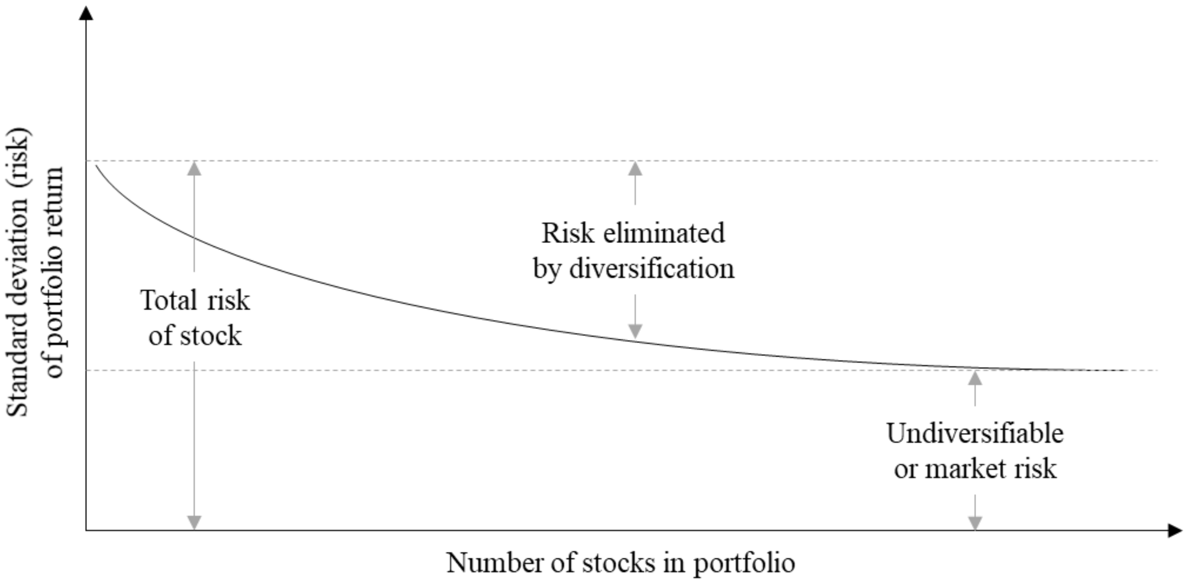


*Figure 1. The effect of diversification (from Lee et al., 2010, p. 80).*

### 2.1.3 The efficient frontier

For a set of investment portfolios, there exists a portfolio that will yield the maximum expected return for a given level of risk, or the lowest possible risk for a given level of expected return. These portfolios are called the efficient frontier and are considered the most efficient of the available portfolios – all other alternatives will result in a higher risk for the same or lower expected return, or a lower expected return for the same or higher level of risk (Lee et al., 2010). The efficient frontier usually has a higher degree of diversification than other portfolios, but also reveals another important knowledge, namely that there is a diminishing marginal return to risk. Hence, adding another risk to a portfolio will not result in an equal increase of expected return. In other words, the marginal effect of adding an extra asset might eventually not result in a sufficient increase of expected return or a sufficient decrease of risk (Francis and Kim, 2013).

The efficient frontier can be visualized as in Figure 2 below (from Lee et al., 2020, p. 78). The figure shows the possible portfolios sets on curve XVYZ. The risk for portfolios X and X’ is equivalent, but the expected return is higher for portfolio X’, why the latter portfolio is preferrable. The curve VY is considered the efficient frontier, where there are portfolios with a maximum level of expected return with a given level of risk, and portfolios with a lowest level of risk for a given level of expected return. All other portfolios are considered less sufficient and will in comparison result in a higher risk or a lower expected return and should therefore be regarded as less desirable.

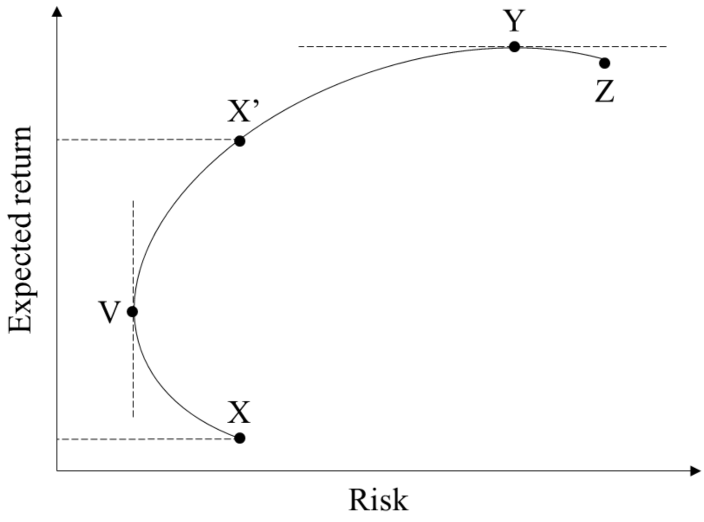


*Figure 2. The efficient frontier (from Lee et al., 2010, p. 78).*

## 2.2 Application of portfolio theory in manufacturing industries

Portfolio theory has been found useful in fields outside of the financial sector, such as electricity planning and production (Delarue et al. 2011; Costa et al., 2017; Scala et al., 2019; Lima et al., 2020), production and sales (Cardozo and Smith, 1983; Ryals et al., 2007), wholesale and retailing (Brzęczek, 2016) and the automotive industry (Kellner and Utz, 2019). Table 1 below displays a brief summary of context, method and results from selected papers, which will be further discussed below. As can be seen in Table 1, portfolio theory has been used in a wide variety of applications since the 1970's and 1980's, from the optimization of product portfolios, sales and supplier portfolios, to analyzing market development and optimizing forecasting techniques.

*Table 1. Application of portfolio theory in manufacturing industries.*

| **Author** | **Context** | **Method** | **Results** |
|---|---|---|---|
| Bar-Lev and Katz (1976) | Electricity planning in oil and gas sector | Efficient frontier of fossil fuel mix determined for nine different regions in USA and compared to the actual operating experience of electric utilities, using secondary data. | Efficient diversification, but the portfolios were characterized with high rate of return and risk. Paying more for fuel mix eliminated uncertainty factors and reduced overall costs. |
| Cardozo and Smith (1983) | Production and sales | Exploratory empirical study using data from 30 organizations to study if portfolio theory can be used as an analytical and planning tool for product portfolio decisions. | Portfolio theory can be used as an analytical and planning tool for product portfolio decisions, and it is possible to create a product portfolio like the efficient frontier. Also, the framework could be used to determine new directions for the allocation of resources. |

| | | | |
|---|---|---|---|
| Barry and Kearney (2006) | Industrial structure and production network | The effect on employment rate by the emergence of multinational enterprises is analyzed using portfolio theory. Ireland is used as a case study, and secondary employment data from annual surveys to all active manufacturing firms is used in the analysis. | The overall diversification of multinational enterprises in Ireland has allowed the overall sector to grow faster without a rise in volatility and risk. |
| Brzęczek (2016) | Wholesale and retailing | Applying mean-variance analysis to a wholesaler in agricultural equipment to analyze model of sales. | An applied model which is used for prediction on total sales and volatility after product category reduction. They found that the model is not applicable if category sales follow a multiplicative seasonality pattern. |
| Kellner and Utz (2019) | Automotive industry | The authors combine mean-variance (costs and supply risk) with sustainability performance and apply the model to a leading premium automotive OEM in Germany to assess supplier selection and order allocation. | Using the model, they could narrow an uncountable number of possible supply portfolios to a large number of optimal portfolio selections, and a web application was developed and helped the selection of the most wanted portfolio. |
| Lima et al. (2020) | Electricity planning and production | Portfolio theory is used to construct a portfolio of solar forecasting techniques in order to reduce predictability errors. The forecasting error of the portfolio is compared to forecasting errors of individual techniques, using data from Spain and Brazil. | The errors from the integration of forecasting techniques in a portfolio was better compared to errors of individual assets. |
| Shehab et al. (2021) | Chemical production plants | Through a case study of six chemical production plants, investment decisions using portfolio theory is compared to investment decisions using traditional net present value and return on investment. | Portfolio theory can be more suitable than net present value and return on investment. Portfolios using monthly variability were better than portfolios using annual variability. |

In manufacturing industries, portfolio theory and mean-variance analysis have been used for both evaluating and forecasting efforts in single organizations (e.g., Kellner and Utz, 2019) but more commonly on a systems level with multiple organizations or regions (e.g., Bar-Lev and Katz, 1976; Cardozo and Smith, 1983; Barry and Kearney, 2006; Shehab et al., 2021). In the papers, portfolio theory has mainly been applied to supporting functions such as purchasing, product development and sales rather than production, and is often used to reduce costs or optimize sales (e.g., Cardazo and Smith, 1983; Brzęczek, 2016; Kellner and Utz, 2019). In some examples, portfolio theory has been applied to discuss the allocation of resources, although these thoughts have been stated to require further development (e.g., Cardazo and Smith. 1983).

The earlier papers where portfolio theory is applied outside the financial sector provide knowledge which is useful in this research project. For example, Bar-Lev and Katz (1976) used portfolio theory to determine the optimal fossil fuel mix for nine different regions in USA and showed, among other things, that purchasing fuel at a higher cost would essentially lead to a more efficient portfolio of fossil fuel since the risk of future variations in fuel price was reduced. Hence, adding extra resources initially in a purchasing process could eventually result in a maintained expected return but with a reduced risk. Furthermore, Cardazo and Smith (1983) found, through an exploratory empirical study, that portfolio theory can be useful in the creation of efficient frontiers in product portfolio decisions. The authors further discuss the effect on resource allocation in a long-term perspective, such as the investments in product lines, but argue that these thoughts must be further developed and adapted to individual organizations' prerequisites and demands (ibid.).

Portfolio theory has been found useful both as an evaluation tool (e.g., Barry and Kearney, 2006) as well as decision-making and forecasting tool (e.g., Lima et al., 2020). These examples are also two of the papers who do not use financial data such as sales or costs in the mean-variance analysis, but instead employment rate and solar irradiance data. The former study used portfolio theory to evaluate the effect on employment rate through the emergence of multinational companies in Ireland, and is therefore different to other studies in terms of not attempting to adapt or develop the mean-variance analysis to a certain setting, or prove its feasibility in other contexts outside financial research (Barry and Kearney, 2006). In the latter example, portfolio theory was instead adapted and used to construct a portfolio of individual solar forecasting techniques, and thereby reduce predictability errors (Lima et al., 2020). One of the main findings was that portfolio theory is an efficient methodology in terms of reducing prediction errors (ibid.).

There are more specific findings in the papers that can be of interest in this research project. Firstly, two papers reflected on the use of variability data in the mean-variance analyses (Brzęzec, 2016; Shehab et al., 2021). Brzęzec (2016) argues that portfolio theory is an unsuitable method to apply when there is a multiplicative seasonality pattern in sales. This is explained by basic assumptions in traditional portfolio theory, that the mean-variance analysis is only applicable when all synergies (hence positive or negative interaction between individual assets) are zero (Bridges et al., 2004; Brzęzec, 2016). Bridges et al. (2004) have on the other hand developed a model where synergies are considered and included, which will be further discussed in section *2.3. Application of portfolio theory in service industries*. Shehab et al. (2021) also reflect on variability data and conclude that more efficient portfolios were obtained when variability data with a shorter timeframe, hence monthly variability instead of annual variability, was applied in the portfolio selection analysis.

Finally, there are examples were the mean-variance analysis has been adapted and developed to include more than two variables. Kellner and Utz (2016) used the mean-variance analysis to assess costs and supply risks to optimal supplier selection and order allocation but added a third variable that was determined important in the selection process, namely sustainability performance. The study found this approach efficient and could reduce an uncountable number of possible supplier portfolios to a large number of optimal portfolios. A web application was thereafter developed and used in order to make the final decision, where other factors besides cost, supply risk and sustainability performance could be considered as well.

## 2.3 Application of portfolio theory in service industries

Portfolio theory has also been applied in service industries, such as biosecurity (Akter et al, 2015; Barnes et al., 2019), ecology and ecosystem services (Alvarez et al., 2017; Eaton et al., 2019; Sierra-Altamiranda et al., 2020), IT and communication systems (Wysocki and Jamalipour, 2011; Bhattacharjee et al., 2020; Miliotis et al., 2020), airline industry (Leon et al., 2013) and healthcare (Bridges et al., 2002; Sendi et al., 2004; Bridges, 2004; Crainich et al., 2017; Baines et al., 2021). Table 2 below displays a brief summary of context, method and results from selected papers, which will be further discussed below. The literature that covers portfolio theory in service industries is generally published more recently compared to portfolio theory in manufacturing industries. For example, portfolio theory in healthcare contexts were first introduced in the late 1990's and early 2000's (O'Brien and Sculpher, 2000; Bridges et al., 2002).

*Table 2. Application of portfolio theory in service industries.*

| Author | Context | Method | Results |
|---|---|---|---|
| Bridges (2004) | Healthcare | A conceptual adaption of the mean-variance analysis to a medical setting with medical interventions, using hypothetical data. | The author provides a discussion on the difference between uncertainty and risk in healthcare. They further add an extra element which occur frequently in medicine: the synergy and covariance between interventions. With synergy, diversification can actually increase risk. |
| Sendi et al. (2004) | Healthcare | Based on portfolio theory, the authors develop an algorithm for budget allocation in healthcare programs which is exemplified with hypothetical data. | The authors argue that portfolio theory has a limited applicability in healthcare, partly due to the effect of diversification in healthcare may be limited because of the size of healthcare programs and uncertainty in the need for resources. They further provide an algorithm for budget reallocation to healthcare programs in need for more resources. |

| | | | |
|---|---|---|---|
| Leon et al. (2013) | Airline industry | A portfolio of available seat miles is determined using mean-variance analysis and mean-value-at-risk analysis. Data from four global airlines for the period 1990-2009 are used to evaluate airline operating profits. | Variability can be reduced through diversification, which have a positive impact on financial performance. Mean-variance and mean-value-at-risk showed to be better alternatives in different settings, where the latter worked better when there is a higher risk of losing capital. |
| Akter et al. (2015) | Biosecurity | A case study of biosecurity in Australia, using survey data as example. The authors combine portfolio theory with a choice experiment study. | A framework for portfolio analysis in the biosecurity sector. Find that resource allocation decisions can be guided through the combination of portfolio theory and choice experiments. |
| Alvarez et al. (2017) | Ecology and ecosystem services | Develops a conceptual framework to help the implementation of empirical portfolios and thereafter use landings data from the Colombian Pacific to exemplify. | A framework with questions that guide the implementation of empirical portfolios, the example is used to visualize how the framework can be used. |
| Miliotis et al. (2020) | IT and communication systems | The authors use portfolio theory to determine the optimal combinations of networking technologies through a proof-of-concept testbed experiments in real wireless environment conditions. | They show that by combining several volatilities, using portfolio theory, the overall throughput volatility that the user experiences can be reduced. |
| Sierra-Altamiranda et al. (2020) | Ecology and ecosystem services | Combine portfolio theory with game theory to develop a conceptual framework for complex planning problems. Provides a hypothetical example. | They develop a framework for complex planning problems with two conflicting objectives: maximizing return and minimizing risk. Portfolio theory is used to generate alternatives and game theory to reduce the number of possible alternatives. A framework for decision making that reduces the number of available choices. |
| Baines et al. (2021) | Healthcare | Use portfolio theory to develop a conceptual framework for evaluating health interventions and health technical assessments. Hypothetical data is used as an example of how the framework could be used. | The analysis can help separate efficient from inefficient interventions and can among other things help as a decision-making tool to choose interventions for particular patient groups. |

In service industries, authors have further developed portfolio theory and the mean-variance analysis to suit various contexts (e.g., Bridges, 2004; Akter et al., 2015). Portfolio theory has been used to discuss allocation of resources, but mainly in terms of financial assets (e.g., Sendi et al., 2004; Akter et al., 2015; Baines et al., 2021). An important difference in the papers regarding portfolio theory in service industries compared to manufacturing industries, is that in several cases the main mission for the service organization or service sector under research is not revenue. For example, the literature in healthcare contexts discuss the allocation of resources with the aim to optimize the use of treatment programs, and studies from ecology and ecosystems services discuss the preservation of biodiversity and conservation of environmental values (e.g., Bridges, 2004; Sierra-Altamiranda et al., 2020). Most papers have in common that resource allocation is discussed with a long-term perspective rather than short-term allocation of resources.

Two of the papers provided in Table 2 above conclude that variability can be reduced when portfolio theory is applied in the specific context, in these cases the airline industry and IT and communication systems (Leon et al., 2013; Miliotis et al., 2020). None of these findings are surprising given the basic mathematical models of portfolio theory, but the findings are of interest in this research project since they provide evidence that portfolio theory can efficiently be applied in sectors outside the financial industry. Miliotis et al. (2020) show that portfolio theory can be used to reduce the volatility experienced by users in cloud-RAN infrastructures, when an optimal portfolio of networking techniques is assembled. In the airline industry, the mean-variance analysis was used to assess financial performance in four global airlines with data from 1990-2009, and it was concluded that through diversification the variability could be decreased with financial gains (Leon et al, 2013). The authors further compare mean-variance analysis to a concept called mean-value-at-risk analysis (ibid.). Value-at-risk is an alternative risk measure, which captures the maximum potential change in value with a given probability over a period of time. The comparison between mean-variance analysis and mean-value-at-risk analysis showed that the former was more effective during normal circumstances, while the latter worked better during periods of steep financial losses (Leon et al., 2013).

Portfolio theory has sometimes been found to provide a large number of possible portfolios, why combinations have been made with other decision-making tools to reduce the number of available alternatives (Akter et al., 2015; Sierra-Altamiranda et al., 2020). In the former paper, the authors investigate how resource allocation decisions of surveillance efforts in biosecurity can be supported through the combination of portfolio analysis and choice experiments. The choice combinations were assessed through a survey administered to 200,000 residents in Australia. Moreover, Sierra-Altamiranda et al. (2020) combine portfolio theory with game theory in order to reduce the number of optimal choices where there are two conflicting objectives: maximizing return and minimizing risk. Through a hypothetical example in ecologic and ecosystem services the authors show that game theory can effectively complement portfolio theory to reduce possible alternatives (Sierra-Altamiranda et al., 2020).

Alvarez et al. (2017) observe the difference of applying portfolio theory in a financial setting compared to natural resource management. In order to guide the portfolio analysis and selection in natural resource management, they develop a set of questions: “1) the nature and the objectives of the portfolio manager, 2) the definition of assets to be included in the portfolio, 3) the way in which return and risk are measured and distributed and 4) the definition of constraints in the programming problem” (from Alvarez et al., 2017, p. 26). The set of questions are thereafter tested in a portfolio analysis using landings data from the Colombian Pacific. Although the questions were developed to help portfolio analysis and selection specifically in natural resource management, the framework could be applied and/or further developed to other service contexts.

Portfolio theory was introduced in health economics in the end of the 1990's and beginning of the 2000's (O'Brien and Sculpher, 2000; Bridges et al., 2002), The framework was further developed to assess medical interventions by Bridges et al. (2004) and has since then been in focus of numerous papers (Bridges and Terris, 2004; Shiell et al., 2009; Crainich et al., 2017; Baines et al., 2021). Bridges (2004) use portfolio theory to show that isolated treatment efforts with a low probability of sufficient results might be efficient in a treatment program since it reduces the overall risk of all treatments. For example, if an antibiotic is estimated to work in only 5 % of all cases, the overall effect of the portfolio of administered antibiotics can be greatly enhanced when this antibiotic is included, since it might be the one medicine that works when all others are not (Bridges, 2004). Furthermore, Bridges (2004) develop the mean-variance analysis to encompass synergy between medical treatments. Traditionally, portfolio theory is only suitable to apply when all synergies equal zero. An important finding when adding synergies to the mean-variance analysis is that diversification, which usually maintains or decreases variation of a portfolio of assets, can actually result in an increased risk of the portfolio due to multiplicative issues.

Efforts have also been made to apply portfolio theory, with a long-term perspective, to the allocation of resources between various treatment programs based on expected results and risks associated with portfolios of interventions (Bridges, 2004; Sendi et al., 2004; Sendi et al., 2021). Sendi et al. (2004) further argues on the ethics in assessing resource allocation based on a combination of treatment programs with various costs and effects, and that one can question the ethical considerations when one population is given a treatment with a lower cost and a lower expected result.

## 2.4 Example of portfolio theory applied in a capacity pooling system

Portfolio theory could be applied to calculate the effect of capacity pools in a healthcare system according to the following example. Consider a healthcare department that consists of four hospital wards, which each plan their capacity independently from the other wards in the example. The expected daily demand for nurses and its variation is shown for each ward in Table 3 below. The demand is assumed to be normally distributed and independent to the other wards in the example. 1.28 standard deviations are required for each unit to reach a service level of 90 %, resulting in a safety capacity of 19 nurses for the hospital department.

*Table 3. Example of capacity pooling in a healthcare department.*

| | Ward 1 | Ward 2 | Ward 3 | Ward 4 |
|---|---|---|---|---|
| Mean number of nurses required on a daily basis | 10 | 15 | 20 | 5 |
| Standard deviation | 3.1 | 3.9 | 5.5 | 2.4 |
| Safety capacity required for a 90 % service level | 4 | 5 | 7 | 3 |

Assume that the hospital department implements a capacity pool with shared safety capacity for the four hospital wards. The expected daily demand for nurses of the entire hospital department is the sum of the expected daily demand for each hospital ward, which in this example is 50 nurses. The standard deviation is instead calculated according to the square root of the sum of the squared standard deviations for the hospital wards, which in this example is 7.8 nurses. Therefore, a total safety capacity of 10 nurses is required to achieve a 90 % service level for the hospital department. The required safety capacity is thereby reduced from 19 nurses to 10 nurses – a reduction by almost 50 % and a reduction of total demand for nurses at the hospital department from 69 nurses to 60 nurses.

If the hospital wards experience a correlation less than one in demand for nurses, the effects of capacity pooling will be even greater. For simplified reasons, assume that two of the hospital wards experience a correlation in demand for nurses. A mathematical example can be used to illustrate how portfolio theory could be used to calculate the effect of correlation. The aggregated variance of two units can be explained with the following equation:

$$\sigma_P^2 = \sigma_1^2 + \sigma_2^2 + 2\sigma_1\sigma_2\rho_{1,2}$$

where $\sigma_P^2$ is the variance of the sum of the random variables 1 and 2, $\sigma_1^2$ and $\sigma_2^2$ are their individual variances, and $\rho_{1,2}$ is the correlation between the random variables 1 and 2 (Francis and Kim, 2013). Assume that the capacity of the two hospital wards is pooled and that the correlation coefficient between the wards is positive, in this example 0.4 (hence, if the capacity requirement at hospital ward 1 is high, the capacity requirement at hospital ward 2 is also high). Furthermore, assume that the standard deviation at hospital ward 1 is 5 nurses and the standard deviation at hospital ward 2 is 8 nurses, resulting in a total safety capacity of 13 nurses when planning is decentralized to each ward. The expected value will not be affected when capacity planning is aggregated. However, the standard deviation of the pooled capacity can be calculated using the above equation, which in this example would be 11. The safety capacity would in this approach therefore decrease from in total 13 nurses to 11 nurses. Assume in the same example that the correlation instead is negative. With a correlation coefficient of -0.4, the safety capacity would instead be 7.5; hence a reduction of 5.5 nurses. To summarize, organizing resources in a capacity pooling system will in a worse case scenario result in the same required safety capacity, but will with a correlation coefficient less than one result in a reduced need for safety capacity.

## 2.5 Research questions

The purpose of this thesis is to develop principles and guidelines for a capacity pooling system in the healthcare sector. In the literature review, portfolio theory has been found a suitable framework for understanding how variations can be managed (Markowitz, 1952). Furthermore, several examples have been found where portfolio theory is applied in contexts outside the financial industry, and more specifically within the healthcare sector, for resource allocation (e.g., Cardozo and Smith, 1983; Sendi et al., 2004; Akter et al., 2015; Baines et al., 2021). However, these studies are all concerned with resource allocations in a long-term perspective, while a capacity pooling approach handles variations in capacity and demand on a short-term basis. To the best of my knowledge, portfolio theory has not been used to assess how variations can be managed in a short-term perspective in healthcare systems. The first question is therefore concerned with how the mathematical models in portfolio theory can be used to design a capacity pooling system:

*Research question 1: How can portfolio theory be used to design a capacity pooling system in the healthcare sector?*

As previously argued, there is a need to improve healthcare capacity planning and management to obtain more efficient organization of healthcare resources (Keskinocak and Savva, 2020). In order to achieve a higher capacity utilization, a shift is required from reactive expensive uses of short-term tools for flexibility in capacity management, to an expanded use of proactive solutions. Preferably a combination of both reactive and proactive tools in a hybrid flexibility solution could be found. In this thesis, it has been argued that an efficient proactive tool is the use of internal capacity pools. It is although important to understand different healthcare departments' need for and use of short-term flexibility tools in capacity management. Different departments might have different solutions for short-term flexibility in capacity management due to the characteristics of the department, where some tools might be preferable over others due to for example costs, available personnel and required knowledge. For example, departments that more frequently use overtime or queuing patients due to the characteristics of the care provided at the department might benefit more from a capacity pooling approach than other departments. To identify the healthcare departments and their needs, the second research question is therefore:

*Research question 2: To what extent are tools for short-term flexibility in capacity management used in different healthcare settings?*

The first two questions are concerned with how a capacity pooling approach can be designed theoretically using portfolio theory and understanding the use of tools for short-term flexibility in healthcare capacity management. The third question is concerned with possible barriers to a capacity pooling system in healthcare settings. There are several theoretical advantages to apply a capacity pooling approach in a healthcare system. For example, capacity pools can result in an enhanced work environment, reduce excessive overtime and reduce the effects of unwanted variations (Noon et al., 2003; Hultberg, 2007; Mahar et al., 2011; Kuntz et al., 2015; Lu and Lu, 2017). However, there might be several reasons to why such an approach might not be applicable in a healthcare context. Therefore, the third research question is stated:

> *Research question 3: What are the perceived barriers for the implementation and use of capacity pools in healthcare systems?*

# 3 Research methodology

*This chapter provides a description of the research design, research process and research methods, followed by a discussion of the research quality.*

## 3.1 Research design

The research methodology should be designed to fulfil the research purpose and provide answers to the research questions. The purpose of this thesis has been defined: "to develop principles and guidelines for a capacity pooling system in the healthcare sector", whereafter three research questions have been formulated:

1. Research question 1: How can portfolio theory be used to design a capacity pooling system in the healthcare sector?
2. Research question 2: To what extent are tools for short-term flexibility in capacity management used in different healthcare settings?
3. Research question 3: What are the perceived barriers for the implementation and use of capacity pools in healthcare systems?

Previous research on capacity pools in healthcare systems have to a large extent been focused on mainly pools of nurses on single units and clinics, and the research is almost exclusively anecdotal (e.g., Rudy and Sions, 2003; Linzer et al., 2011; Bates, 2013; Lebanik and Britt, 2015). There is a lack of systematic research with a holistic focus on the capacity management of all professions within a healthcare system consisting of several healthcare organizations (Keskinocak and Savva, 2020). According to Bryman and Bell (2011), a mixed-methods approach can be deployed when the available theory within a research field is insufficient to build hypotheses. Therefore, the approach in this research project will be systematic, using mixed-methods with predominantly quantitative studies. The Priority-Sequence Model according to Morgan (1998) has been used as source of inspiration, see Figure 3. The approach in the research project has been what is defined as a principal quantitative approach with a complementary preliminary qualitative approach. Hence, qualitative methods were used to help guide the data collection in the quantitative study.

***Priority Decision***

| ***Sequence Decision*** | Principal Method: ***Quantitative*** | Principal Method: ***Qualitative*** |
|---|---|---|
| Complementary Method: ***Preliminary*** | 1. Qualitative Preliminary<br>qual → QUANT<br><br>**Purposes:** Smaller qualitative study helps guide the data collection in a principally quantitative study.<br><br>Can generate hypotheses, develop content for questionnaires and interventions, etc.<br><br>**Example:** Focus groups help to develop culturally sensitive versions of a new health promotion campaign. | 2. Quantitative Preliminary<br>quant → QUAL<br><br>**Purposes:** Smaller quantitative study helps guide the data collection in a principally qualitative study.<br><br>Can guide purposive sampling, establish preliminary results to pursue in depth, etc.<br><br>**Example:** A survey of different units in a hospital locates sites for more extensive ethnographic data collection. |
| Complementary Method: ***Follow-Up*** | 3. Qualitative Follow-Up<br>QUANT → qual<br><br>**Purposes:** Smaller qualitative study helps evaluate and interpret results from a principally quantitative study.<br><br>Can provide interpretations for poorly understood results, help explain outliers, etc.<br><br>**Example:** In-depth interviews help to explain why one clinic generates higher level of patient satisfaction. | 4. Quantitative Follow-Up<br>QUAL → quant<br><br>**Purposes:** Smaller quantitative study helps evaluate and interpret results from a principally qualitative study.<br><br>Can generalize results to different samples, test elements of emergent theories, etc.<br><br>**Example:** A statewide survey of a school-based health program pursues earlier results from a case study. |

*Figure 3.The Priority-Sequence Model according to Morgan (1998), p. 368.*

## 3.2 Study object

Sweden is divided into 21 politically controlled regions who each are responsible for the organization and provision of healthcare to its inhabitants. The study object in this research project is Region Västra Götaland, a healthcare provider in Sweden which, due to its organization and size, is comparable to other healthcare systems. It is one of the largest regions with 1.7 billion residents, approximately 17 % of Sweden’s population (Regionfakta.com, 2021). The region controls five multihospital groups, including university hospitals and rural hospitals, that provides healthcare at 16 different sites. The region also controls 202 primary health centers and 28 emergency centers organized under one administration called Närhälsan. In addition, there are four private hospitals with contractual agreement. Figure 4 below shows the distribution of the hospitals in Region Västra Götaland.


*Figure 4. Region Västra Götaland.*

Sahlgrenska University Hospital (SU), one of the five multihospital groups in Region Västra Götaland, is the largest university hospital in Sweden, and provides healthcare at five different sites. The hospital is organized in 50 specialty departments, grouped in six divisions, and counts for all the specialties in the region. SU has approximately 17,000 employees, 2,000 care beds and answer for 50 % of the total healthcare costs in the region. A department manager is responsible for the department's capacity planning, and normally have one or several unit and/or section managers organized within the department. In general, the unit manager is responsible for nurses and assistant nurses, while the section manager is responsible for physicians. A unit is typically a hospital ward or hospital reception, and a section usually serves several units and/or receptions within a department. SU has an internal staffing pool consisting of mainly nurses and assistant nurses. Figure 5 provides a general description of SU's organization.

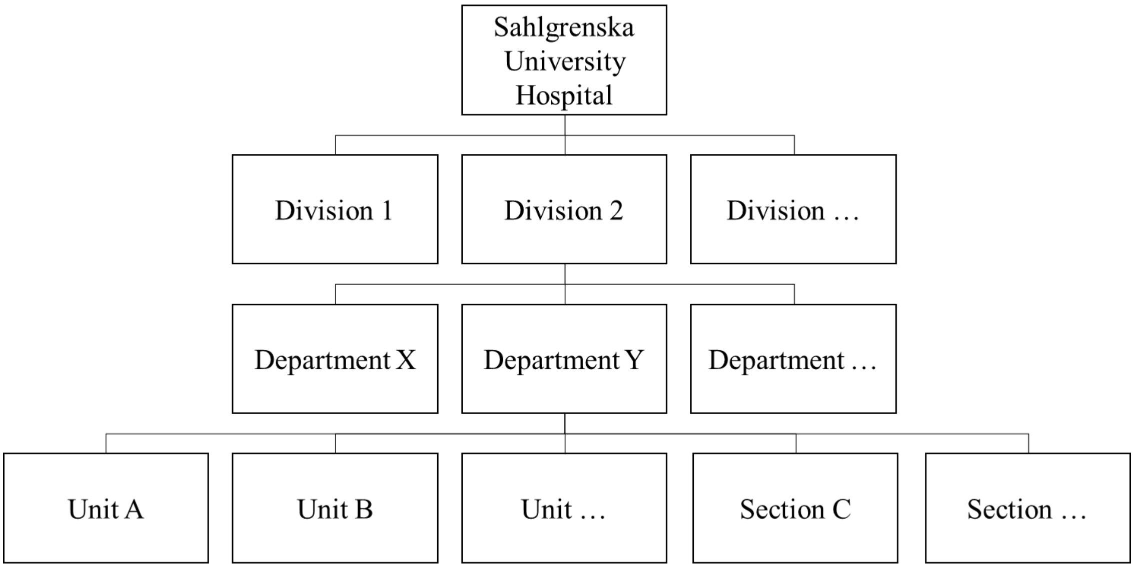


*Figure 5. The organization of Sahlgrenska University Hospital.*

The organization and classification of healthcare in Sweden is controlled by The National Board of Health and Welfare and described in the Swedish Health and Medical Service Act. Healthcare departments can be classified based on mainly four dimensions:

- *Specialty*; mainly 1) surgical, 2) medical or 3) psychiatric care. In Sweden the classification of specialties is controlled by The National Board of Health and Welfare (SOSFS, 2015:8).
- *Length of patient stay*; mainly 1) inpatient or 2) outpatient care. Inpatient care usually requires admission, while outpatient care can be delivered without overnight stay. The definition of inpatient and outpatient care is defined in the Swedish Health and Medical Service Act (HSL, 2017:30).
- *Level of urgency*; mainly 1) acute or 2) planned care. Acute patients require immediate attention, while planned care can be planned ahead (Socialstyrelsen.se, 2021).
- *Type of organization*; 1) primary care center, 2) rural hospital or 3) university hospital. University hospitals have educational commitments, conduct extensive research in close collaboration with universities, and normally have a higher degree of specialization compared to rural hospitals. Primary care centers account for basic healthcare provision. (Socialstyrelsen.se, 2021).

## 3.3 Research process and methods

Two studies have been performed within this research project to answer the research questions, resulting in three papers, see Figure 6 below. The first research question is concerned with how a capacity pooling approach can be designed in a healthcare setting, with the help of portfolio theory. To answer the first research question, a literature review has therefore been conducted. Research questions two and three are concerned with tools for short-term flexibility in healthcare capacity management, and barriers to capacity pooling in healthcare settings, where a pre-study followed by a questionnaire study have been conducted. A more detailed description of the research methods and data analysis is provided in the appended papers.

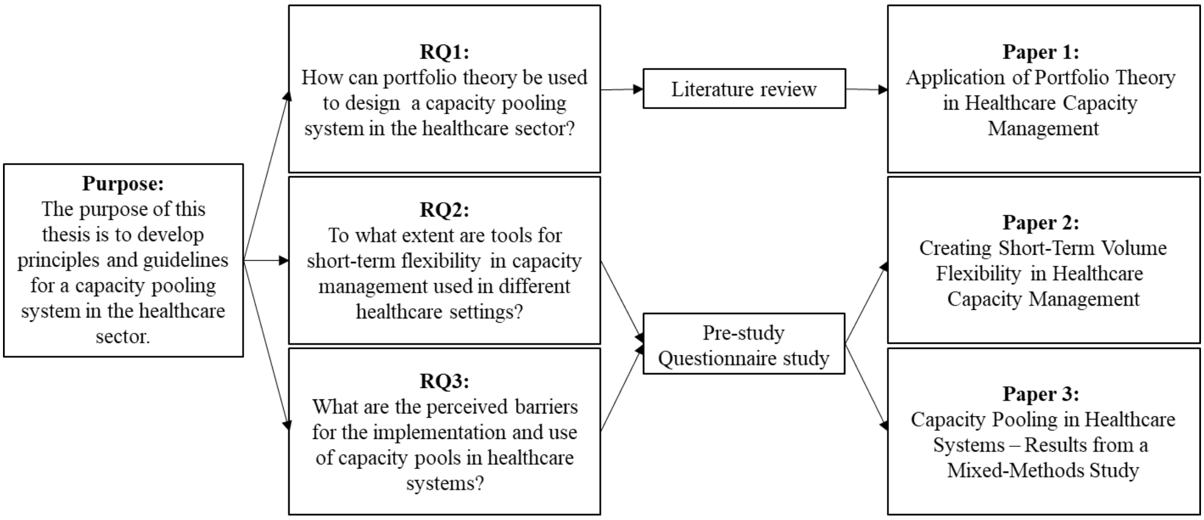


*Figure 6. The research questions and their relation to the studies.*

### 3.3.1 Literature review

A literature review was conducted with focus on portfolio theory in general, in order to generate a basic knowledge of the concept and the research field. Thereafter, particularly creative applications of portfolio theory in manufacturing and service industries were in focus of the literature search. Although the literature review cannot be considered a systematic literature review according to strict definitions, it broadly followed the steps of a systematic literature review proposed by Bryman and Bell (2011). Relevant papers were searched for in two databases: EBSCO and ScienceDirect. Keywords such as “portfolio theory”, “application portfolio theory”, “portfolio theory service” were used. Relevant articles were chosen based on their titles and abstracts. Literature reviews of capacity pools in healthcare systems and short-term flexibility of capacity management in healthcare systems has also been conducted.

### 3.3.2 Pre-study

The pre-study had an inductive methodological approach and aimed to create an understanding of the research field, which would be used to generate hypotheses in the questionnaire study (Bryman and Bell, 2011). An interview study was conducted in 2018 with ten specialty department managers in Region Västra Götaland. The focus of the interviews was capacity planning in general and capacity pooling in particular. The managers were employed at Sahlgrenska University Hospital and the primary care center organization Närhälsan. The specialty departments were classified according to the characteristics of healthcare departments described in section *3.2. Study object*, and department managers where thereafter chosen in order to ensure sample representativeness in the study. The department managers were asked to participate in the interviews with a holistic view of the capacity planning efforts at the department, with all types of professions in mind. Questions were asked during the interview on for example the perceived need for pooling different categories of staff, if/how pooling is a part of the current capacity management process, and if/how there were plans to develop the pooling perspective within capacity management. Questions were also asked regarding the tools they use for short-term flexibility in capacity management. Three authors were present during most of the interviews, and all interviews were recorded and transcribed. The interviews were analyzed using content analysis (Graneheim and Lundman, 2004), see section *3.3.4. Data analysis*, and resulted in six barriers to capacity pooling in healthcare systems. Moreover, the interview study provided an understanding for the use of short-term tools for volume flexibility in capacity management.

### 3.3.3 Questionnaire study

Based on the results from the pre-study, a web-based questionnaire was developed and sent to all department, unit and section managers in Region Västra Götaland. General questions regarding if the department has mainly acute/planned care, inpatient/outpatient care, and surgical/medical/psychiatric care were asked. Furthermore, questions were asked regarding to what extent managers use the seven identified tools for short-term capacity management: overtime, temporary staff from internal phone lists, permanent staff moving across units, internal staffing pools, external staffing agencies, queuing patients, and purchase care from external healthcare providers. The questionnaire also consisted of 22 items in six different categories of potential barriers for capacity pooling identified in the pre-study: competence, geography, culture, system, planning, and recruitment. A seven-point Likert scale was used to record answers for each short-term flexibility tool and for each item, where a lower value meant a lower level of usage and a lower level of agreement with the statement. The respondents were also able to provide comments on all questions.

Before distribution, the questionnaire was tested on both the interviewees from the pre-study, as well as ten selected managers (unit, section, and department managers), whereafter minor adjustments were made. The questionnaire was thereafter sent to 1144 healthcare managers in Region Västra Götaland in the spring of 2019. The questionnaire had a response rate of 41.3%, and the distribution of specialty types, admission types, level of urgency, types of organization, and manager types represented by the participating respondents was in line with the distribution of the different department types in Region Västra Götaland, see descriptive statistics in Table 4.

*Table 4. Descriptive statistics of the sample*

| Parameter | Number of Respondents |
|---|---|
| **Specialty** | |
| Surgical | 98 |
| Medical | 285 |
| Psychiatric | 75 |
| Other | 15 |
| **Admission** | |
| Mainly inpatient care | 236 |
| Mainly outpatient care | 237 |
| **Level of urgency** | |
| Mainly acute care | 211 |
| Mainly planned care | 262 |
| **Type of organization** | |
| Primary care center | 75 |
| Rural hospital | 216 |
| University hospital | 182 |
| **Manager type** | |
| Unit manager | 321 |
| Section manager | 46 |
| Department manager | 106 |

### 3.3.4 Data analysis

The transcribed data from the pre-study was analyzed using content analysis (Graneheim and Lundman, 2004). The content analysis provided an overview of the perceived potential barriers of capacity pooling in Region Västra Götaland. The interview data also provided guidance for the use of short-term tools for volume flexibility in capacity management.

The questionnaire data regarding short-term tools for volume flexibility in capacity management was analyzed using regression models (for further description see paper 2). The questionnaire data regarding barriers to capacity pools (for further description see paper 3) was initially analyzed using a confirmatory factor analysis to see if the six barrier types resulting from the content analysis could be confirmed (Hair et al., 2014). As the barrier types could not be confirmed, a principal component analysis was performed to explore new groups of barriers (ibid.). The new barriers were identified to be specialization, community view, recruitment difficulties, and physical distance. Finally, the difference in perceived barrier heights between different manager types was analyzed through a two-way mixed analysis of variance (ANOVA).

## 3.3.5 Research timeline

Figure 7 below shows the research timeline of the project.

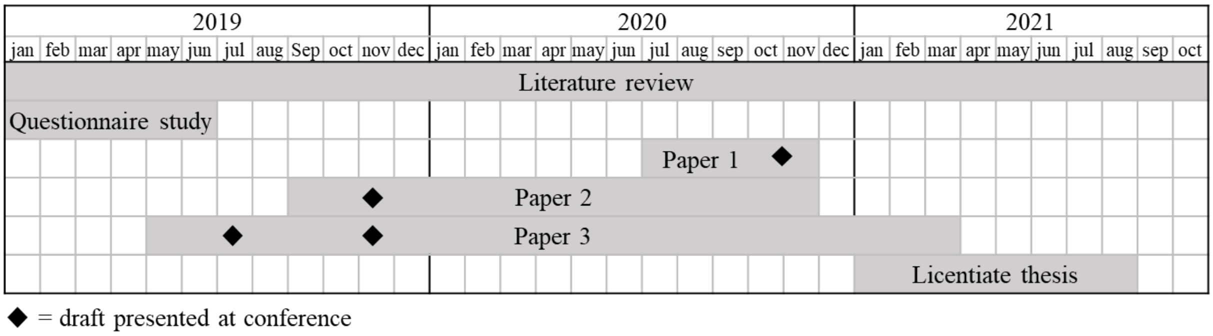


*Figure 7. The research timeline.*

## 3.4 Research quality

Research quality can be assessed according to three criteria: internal validity, external validity and reliability. These will be further discussed below.

## 3.4.1 Internal validity

Internal validity is concerned with to what extent cause-and-effect relationships have been found, and if a study has made it possible to eliminate other explanations of the results (Taylor, 2013). Several measures have been taken in order to ensure internal validity in this research project. Firstly, the questionnaire was consulted with the department managers who participated in the pre-study, as well as with several other managers at Sahlgrenska University Hospital (unit, section, and department managers) whereafter minor changes were made in the questions before distribution. Moreover, the distribution of respondents in the questionnaire was in line with the distribution of the specialty types, admission types, level of urgency, types of organization, and manager types, why we assumed a non-response bias. However, as with all questionnaire studies, bias in respondents can occur due to for example interest in the research area (Bryman and Bell, 2011). We therefore attached a cover letter with the questionnaire to emphasize the importance of the results, not only for the research project but also from top management at Region Västra Götaland, and reminded participants multiple times to respond to the questionnaire. Finally, as the majority of the questions were single choice questions, the respondents were given the opportunity to comment on all questions if they wanted to add an explanation or elaborate on a certain answer.

### 3.4.2 External validity

External validity is concerned with the generalizability of the results (Taylor, 2013). The studies in this research project have been performed in a Swedish healthcare context. However, both the identified barriers to capacity pools and the short-term tools for flexibility in capacity management have been found in international literature (with the exception of barriers related to physical distance, since most studies have been performed on isolated units or clinics). Therefore, the results are supported by international research and are not considered to be specific and limited to a Swedish healthcare context. Moreover, the respondents in the initial interview study were department managers, while the questionnaire was distributed to managers on department, section, and unit levels, which theoretically could be an external validity issue. Department managers who participated in the pre-study were all asked to consider all professions in a holistic departmental perspective. Our analyses did not show a difference in results between manager types, why we believed that difference in manager composition between the interview study and questionnaire study did not matter.

### 3.4.3 Reliability

Reliability is according to Bryman and Bell (2011) concerned with the consistency of measures. Reliability issues were managed through the validation of the questionnaire with the interviewees and other unit, section, and department managers before distribution to all managers in Region Västra Götaland, as described above in section *3.4.1. Internal validity*. Furthermore, reliability was not considered an issue since results from the questionnaire study regarding both short-term tools for flexibility in capacity management and barriers to capacity pooling were supported through findings in international literature.

### 3.4.4 Ethical considerations

Bryman and Bell (2011) states four main areas of ethical considerations: whether there is harm to participants, whether there is lack of informed consent, whether there is an invasion of privacy, and whether deception is involved. The respondents in the questionnaire study were informed of their anonymity and that participation is voluntary. A cover letter was also provided, signed by the participants in the research project, where the respondents were informed of the purpose of the study and how the data would be handled and stored.

# 4 Summary of appended papers

*In this section, the papers included in the licentiate thesis are briefly summarized, with a short description of the student's participation and responsibility in each paper.*

## 4.1 Paper 1: Application of Portfolio Theory in Healthcare Capacity Management

Paper 1 sets the foundation of the research project, with an analysis of how portfolio theory can be applied in a capacity pooling approach in healthcare systems. In the conceptual paper, a brief description is provided of how portfolio theory has been used in sectors outside of the financial industry, such as the biosecurity and electricity planning fields. The paper continues with a numerical example, using fictious data, of how a mean-variance analysis can be performed to illustrate different pool configurations and the effect on capacity utilization. It also shows, using the numerical example, the impact of the correlation coefficient and argues that a capacity pooling approach theoretically will result in a higher capacity utilization and higher service level for all pool configurations with a non-perfectly positive coefficient correlation. The study concludes with a discussion regarding the practical usefulness of this methodology in the healthcare context. The results of the paper are intentioned to be used as a theoretical baseline of how the mean-variance analysis can be used to determine the organization of capacity pools.

The idea for the paper was raised during the early beginning of the research project and was further developed during a period of time. An early version of the paper was presented at the 2020 PLAN's Forsknings- och tillämpningskonferens in Södertälje. When an opportunity was provided to submit a paper to a special issue for the deployment of industrial management methods in healthcare services, in the *International Journal of Environmental Research and Public Health*, the paper was further developed and submitted to the journal in September 2020. The paper was accepted by the guest editor Professor Paul Lillrank after a major revision in January 2021. The paper was co-authored with Björn Lantz, where Carina Fagefors was the project leader of the paper and conducted the literature review, while Björn Lantz provided the fictious numerical example and mean-variance analysis.

## 4.2 Paper 2: Creating Short-Term Volume Flexibility in Healthcare Capacity Management

In this paper, tools for short-term flexibility in healthcare capacity management is investigated. Through a literature review, it was found that the main tools used to create short-term volume flexibility in healthcare systems include overtime, temporary staff from internal calling lists, moving staff across units, internal staffing pools, external staffing agencies, queuing patients, and purchasing care from external providers. A questionnaire was developed and distributed to 1144 managers in Region Västra

Götaland. Data from the questionnaire was used to investigate what tools for short-term flexibility in healthcare capacity management that are more frequently applied for different types of healthcare departments, clustered into either mainly acute or non-acute care, either university hospital, rural hospital, or primary care center, either inpatient or outpatient care, and type of specialty. Data were analyzed using multiple regression analysis. Several significant tendencies were found, including that acute units use overtime and internal staffing pools to a larger extent, and queuing patients and external providers to a lesser extent than planned units. The insights from the paper are important to consider when a capacity pooling approach is developed. For example, departments that frequently apply the use of overtime will likely benefit from instead using staff from capacity pools. These results serve as a steppingstone towards a more thorough understanding of efficient capacity management in healthcare systems

The idea for this paper was developed during the same process as paper 3. An early version of the paper was presented at PLAN's Forsknings- och tillämpningskonferens in Linköping in October 2019 by Carina Fagefors. The paper is co-authored with Björn Lantz and Peter Rosén. The paper was submitted to the above-mentioned special issue for the deployment of industrial management methods in healthcare services in *International Journal of Environmental Research and Public Health*. The paper was submitted in September 2020 and accepted after a major revision in December 2020.

## 4.3 Paper 3: Capacity Pooling in Healthcare Systems – Results from a Mixed-Methods Study

This paper examines the potential barriers for capacity pooling in healthcare systems. The study was conducted using two methods. One pre-study was initiated before Carina Fagefors was included in the research group, which was an interview study with healthcare department managers in Region Västra Götaland. Questions were asked regarding potential barriers to capacity pooling, and the transcribed interviews were analyzed using content analysis. The pre-study resulted in 22 types of barriers for capacity pooling, which were grouped into six categories: competence, geography, culture, system, planning, and recruitment.

After the interview study was completed, Carina Fagefors joined the research team. Based on the results from the content analysis, a questionnaire was developed and distributed to all section, unit, and department managers in Region Västra Götaland, in total 1144 managers. The questionnaire had a response rate of 41.3 %. The data were analyzed using confirmatory factor analysis, explorative principal component analysis, and analysis of variance. The six categories of barriers above could not be confirmed and instead four new barriers were formulated, namely specialization, community view, recruitment difficulties and physical distance. Two of the barriers were found to be perceived higher, namely recruitment difficulties and physical distance. The important managerial implications from the study is that in order to implement an efficient capacity pooling approach in healthcare systems, the four barriers must be considered and if possible managed with specific actions, or pool configurations should be created where the barriers are not an issue.

An early version of the paper with results from the interview study was presented at PLAN's Forsknings- och tillämpningskonferens in Jönköping in October 2018 by Björn Lantz and Peter Rosén. A developed version of the paper with results from the questionnaire study was presented at the 31st NOFOMA Conference in Oslo by Carina Fagefors and Björn Lantz. The paper has been co-authored with Björn Lantz, Peter Rosén and Levi Siljemyr. Carina Fagefors was the project leader of the questionnaire study. The paper has been submitted to a respected journal and is awaiting the review process.

# 5 Discussion

*In this chapter, the results of the research projects are discussed. The research questions are answered, followed by a general discussion on the possibilities and challenges of using capacity pools in healthcare systems.*

The purpose of this thesis was to develop principles and guidelines for a capacity pooling system in the healthcare sector. Three research questions were formulated, and a pre-study followed by a questionnaire study and a literature review have been conducted to answer the questions, resulting in three papers. Below, the three research questions will be discussed based on the results of the studies.

> *Research question 1: How can portfolio theory be used to design a capacity pooling system in the healthcare sector?*

Paper 1 is concerned with the theoretical implications for a capacity pooling approach in healthcare systems. Our results show that portfolio theory could be applied in a sector outside the financial industry and use data that is not of financial nature in the mean-variance analysis. Our findings are supported by literature in both manufacturing and service industries (e.g., Brigdes, 2004; Barry and Kearney, 2006; Lima et al., 2020). Our paper provides important knowledge on theoretical advantages with using portfolio theory to design capacity pools, and the possible gains in capacity utilization of an entire system when allocating available resources to capacity pools. It was concluded that, using a mean-variance analysis, pooling is theoretically an efficient approach to manage and organize capacity, and that higher capacity utilization can be achieved with the same or higher service level. Previous literature has provided guidance on resource allocation with the help of portfolio theory but has been focused on strategic long-term allocation of mainly financial resources rather than short-term flexibility in capacity management (e.g., Sendi et al., 2004; Akter et al., 2015; Baines et al., 2021). Shehab et al. (2021) argue that variability on a short-term monthly basis provided more efficient portfolios than variability on an annual basis, which further supports the use of portfolio theory in short-term allocation of capacity.

The results of the paper show that the effects of pooling will be stronger with a lower correlation in capacity requirements between units allocated to the same pool, which means that when a unit during a period of time requires less capacity, while another unit during the same period of time requires more, the total capacity utilization of the two units will be improved if the units are allocated to the same capacity pool. Positive effects will be achieved also with units that have a higher correlation in capacity requirements, since, when several sources of variability are aggregated, the relative influence of variability will decrease (Terwiesch et al., 2011). Besides the mathematical implications for the effect of diversification, the reduced variability has also been proven in the literature (e.g., Bar-Lev and Katz, 1976; Leon et al., 2013; Miliotis et al., 2020).

The variations in capacity requirements will have a limited effect on the healthcare system when the resource allocation is aggregated (Terwiesch et al., 2011; Kuntz et al., 2015), which we also prove through our hypothetical example in paper 1. However, studies show that variability data must be used wisely and for example multiplicative seasonality and synergies between assets must be considered when constructing portfolios (Bridges, 2004; Brzęczek, 2016). Portfolio theory assumes zero synergies between assets, but for example Bridges (2004) developed a model where synergies are accounted for, which proved that diversification could have the opposite effect when synergies exist between assets. Moreover, Shehab et al. (2021) show that variability data with a shorter timeframe (monthly compared to annually) provided more efficient portfolios. Therefore, constructing capacity pools in healthcare systems must take these variability considerations into account.

Although the theoretical findings might imply that a large number of units in a capacity pool will improve the total capacity utilization, the marginal effects on the service level diminish with an increased number of units in a pool (Cattani and Schmidt, 2005). The next step to generate principles and guidelines for a capacity pooing approach was therefore to find where in a healthcare system capacity pools will result in most benefits when implemented. This could be achieved through understanding the use of proactive and reactive tools for short-term flexibility in capacity management for different healthcare departments, where a move from reactive to proactive use of capacity would improve the capacity utilization of the entire system, which further leads to the second research question of this project.

> *Research question 2: To what extent are tools for short-term flexibility in capacity management used in different healthcare settings?*

Paper 2 is concerned with short-term flexibility tools in healthcare capacity management and identifies which types of healthcare units and departments that frequently apply inefficient reactive solutions. There are several examples of reactive tools that are used to cope with insufficient capacity in healthcare systems, which can be both harmful to employees and threaten patient safety, such as the use of overtime and queuing patients. Firstly, the excessive use of overtime can have a negative impact on work environment and stress levels among employees (Lu and Lu, 2017; Sebastiano et al., 2017). Secondly, queuing patients in emergency departments or on waiting lists can, besides the obvious suffering of the patients, lead to costs of poor quality (Chow et al., 2011; Dobson et al., 2011). In our study, these tools have all been shown to be frequently applied to cope with scarce capacity in different types of healthcare units and departments. The findings of the paper show for example that healthcare departments that provide mainly acute care have tendencies to more frequently apply an extensive use of overtime due to the limitations in timeframes that characterize acute care. Departments that on the other hand provide a larger amount of planned care is more inclined to queue patients as a tool for short-term flexibility.

These types of units could benefit from moving towards a proactive approach to capacity management, such as the use of capacity pools.

In our study, we also found tools for short-term flexibility in healthcare capacity management with a more proactive nature, such as calling temporary staff from internal phone lists and moving permanent staff across units (e.g., Jack and Powers, 2004; Jack and Powers, 2009; Qin et al., 2015; Svalund et al., 2018). Although these types of tools are generally more desirable than reactive tools, they are not applicable to all healthcare departments during all times. These types of tools are dependent on the availability of cross-trained personnel and temporary staff at individual units or clinics, which can vary over time, and are therefore more difficult to systematize. Moreover, having cross-trained personnel is associated with high costs and time wastage (Olhager, 1993; Hopp and van Oyen, 2004; Roach et al., 2011; Bates, 2013). The use of capacity pools is therefore an important tool also for these types of departments, although they might not be prioritized in the allocation to a capacity pool if other proactive tools are available.

Although units would theoretically benefit from moving towards a proactive use of capacity pools, there might be barriers to the implementation and use of pools. Hence, practical barriers to capacity pooling must be considered, and if barriers related to capacity pooling exceeds the potential benefits of pooling efforts must be made to either overcome the barriers or exclude units from the capacity pooling approach. This leads to the third research question of this project.

> *Research question 3: What are the perceived barriers for the implementation and use of capacity pools in healthcare systems?*

Paper 3 is concerned with potential barriers to a capacity pooling approach, which is an important knowledge when defining guidelines on how to design capacity pools in healthcare systems. Four barriers were found: barriers related to specialization, barriers related to community view, barriers related to recruitment difficulties, and barriers related to physical distance. Three of the barriers found in our study are supported by findings in the literature (e.g., Cavouras, 2002; Inman et al., 2005; Dziuba-Ellis, 2006; Bates, 2013). The fourth barrier, namely physical distance, could not be found in the literature since most studies are concerned with isolated units or clinics where physical distance is not an issue. Furthermore, two of the barriers were found in our study to be perceived higher, namely barriers related to recruitment difficulties and barriers related to physical distance. Interestingly, the analysis could not confirm a difference in perceived barrier heights between manager types, which indicate a collective view on barriers to a capacity pooling approach among managers on different levels and for different professions in a healthcare system. Implementing a capacity pooling approach is thereby eased when managers in general agree on where efforts should be focused, and when there is a priority sequence in which of the barriers to target in the initial phase of the implementation and use of capacity pools.

Managing the identified barriers is of great importance for a successful implementation and use of capacity pools in healthcare systems. Efforts should be initially focused on the two barriers found to be perceived higher, namely barriers related to recruitment difficulties and barriers related to physical distance. The former barrier type could be handled through for example pay supplements, scheduling flexibility, independence, and skill development (Cavouras, 2002; Dziuba-Ellis, 2006; Larson et al. 2012; Bates, 2013; Lebanik and Britt, 2015), while barriers related to physical distance could be managed with for example digital solutions where applicable, such as in primary care centers, or through organization of pools consisting of units within close geographical distance. Efforts should thereafter also be focused on the two barriers that were perceived lower. Barriers related to specialization can for example be managed through orientation programs and standardization of routines and practices (Roach et al., 2011; Adams et al., 2015), while barriers related to community view could be overcome through appropriate unit orientation and supporting the dedicated pool staff (Rudy & Sions, 2003; Roach et al., 2011). When barriers are successfully managed, or considered when pool configurations are decided, there are prerequisites for the implementation and use of capacity pools in healthcare systems.

The studies in this research project have shown how portfolio theory can be used to dimension capacity pools, which types of units that frequently apply different types of short-term flexibility tools in healthcare capacity management, and potential barriers to a capacity pooling approach in healthcare systems. These findings are important to consider when developing and dimensioning a capacity pooling system in settings that have the characteristics of healthcare, namely the simultaneous production and consumption of the service provided and the large variations in both capacity and demand. As shown in paper 1, there are theoretical advantages of organizing a system's available resources in capacity pools, and capacity utilization of the entire system will increase. However, the marginal effects of adding a unit to a capacity pool will decrease with an increasing number of units allocated to the pool (Cattani and Schmidt, 2005; Terwiech et al., 2011). In paper 2 we therefore investigated to what extent different healthcare departments use proactive and reactive tools for short-term flexibility in capacity management. Departments that frequently apply reactive solutions, such as an extensive use of overtime, queueing patients beyond acceptable waiting times, and use costly external staffing agencies, would benefit from a change in how short-term allocation of capacity is managed. When designing a capacity pooling approach in a healthcare setting, the departments that mainly use reactive tools should therefore be prioritized. Potential barriers to capacity pools should thereafter be considered and managed if possible, for example with digital solutions to overcome barriers related to physical distance, whereafter the pool configurations might be changed. To summarize, the approach used in paper 1 can be used as a theoretical baseline for the theoretically optimal configuration of capacity pools in a healthcare system, after which the findings in paper 2 and 3 help with practical guidelines to prioritize and design capacity pools in healthcare settings. However, there are challenges that still must be managed in order to develop efficient capacity pools.

The example provided in paper 1 was constructed using hypothetical data. For an efficient design of capacity pools in specific healthcare settings such as Region Västra Götaland, real data must be used. A possible approach for designing capacity pools using real data have been found in the literature. Alvarez et al. (2017) proposed a framework for guiding a portfolio analysis in contexts outside the financial sector, with four questions to be answered (see section *2.3. Application of portfolio theory in service industries*). These questions can help circumscribe challenges specific for healthcare settings, with possible constraints (such as barriers to capacity pooling) that must be considered in the formation of capacity pools. When conducting the mean-variance analysis, there might be factors that should be added in the analysis besides risk and expected return due to their importance. Kellner and Utz (2019) provide such an example, where sustainability performance was determined essential in the automotive industry and therefore added to the mean-variance analysis. Finally, when conducting a mean-variance analysis, several studies have found that a large number of possible portfolios might be generated. In order to help the decision-making process, other methods such as game theory and choice experiments have been used to complement portfolio theory to limit the number of alternative options (Akter et al., 2015; Sierra-Altamiranda et al., 2020). Lessons learned from paper 2 and paper 3 could be used in the process of limiting number of available capacity pooling configurations.

There are not only potential benefits to be gained with the implementation and use of capacity pools, but the literature reveals identified challenges. For example, studies have shown potential patient safety issues and a stressful work environment for employees working in a capacity pool (Cavouras, 2002; Rudy & Sions, 2003; Bates, 2013; Adams et al., 2015). Furthermore, other research has shown that although the organization of capacity into pools result in cost savings, there are other alternative ways of working such as optimizing team configurations (Rowse et al., 2013). Song et al (2015) found that when implementing capacity pools in an emergency department, the patient length of stay actually increased. The cause of this result is further discussed in the paper and argued to be that when all patients were pooled to the same queue, the physicians lost sense of responsibility for a smooth patient turnover (ibid.), which highlights the need to take behavioral considerations into account (Boudreau et al., 2003; Donohue et al., 2020). These results were not found in our study of potential barriers to capacity pools but should regardless be considered and managed when implementing a pooling approach.

Although studies have shown potential challenges to capacity pooling, there are several theoretical benefits with capacity pools. As previously stated, a capacity pool is a tool towards achieving an efficient match between available resources and healthcare demand which in turn can lead to shorter waiting times for patients, increased service level, and enhanced patient safety (Lupien et al., 2007; Kc & Terwiesch, 2009; Mahar et al., 2011; Kuntz et al., 2015; Alvekrans et al., 2016). A recent example where a capacity pooling approach has been tested, although not deliberately and voluntarily, is the recent covid-19-pandemic. Within a short timeframe, the available capacity of intensive care beds doubled when inhouse staff were reallocated to parts of the system where the need for resources was unusually high (Businessinsider.com, 2020; Thelocal.com, 2020; Zangrillo & Gattinoni, 2020). Moreover, if the effect of variability is mitigated, the workload will be experienced as more manageable, which in turn can lead to an enhanced and less stressful work environment (Hultberg, 2007). Finally, a move towards a more proactive use of capacity will lead to a decrease in the use of reactive tools for short-term allocation of capacity. For example, Lu and Lu (2017) argue that capacity pools can be used to reduce excessive overtime, leading to cost savings and higher employee satisfaction.

# 6 Conclusion and future research

*In this chapter, the licentiate thesis is concluded, followed by an elaboration on possible areas for future research.*

## 6.1 Conclusions

The purpose of this thesis was to develop principles and guidelines for a capacity pooling system in the healthcare sector. Three research questions were formulated. A pre-study followed by a questionnaire study and a literature review have been conducted to answer the research questions, resulting in three papers. The findings in the papers have provided examples on how portfolio theory could be used to design capacity pools, knowledge on the use of proactive and reactive tools for short-term flexibility solutions in healthcare capacity management, and perceived barriers to a capacity pooling approach in healthcare systems.

The findings will have managerial implications for healthcare managers when deciding on a capacity pooling approach. The results can help guide healthcare managers in how to design capacity pools, which types of healthcare departments that should be prioritized in capacity pooling allocation, and what barriers to consider when implementing and using capacity pools. The results can help managers in prioritizing efforts to design pools and overcome barriers to pooling. The research has been conducted on a system level, with several types of healthcare providers, specialties, professions, and levels in the organization. Interestingly, no difference in perceived barriers between manager types could be found, which further ease the implementation and use of capacity pools in healthcare systems.

The findings in this project contribute to the existing research in several ways. First of all, previous studies on capacity pools in healthcare settings is to a large extent anecdotal, focused on isolated units or clinics and on pools of nurses (e.g., Rudy and Sions, 2003; Linzer et al., 2011; Bates, 2013; Lebanik and Britt, 2015). Keskinocak and Savva (2020) argue that there is a need for a holistic approach on capacity management in healthcare systems and Leeftink et al. (2020) highlight the importance of researching temporary capacity changes in healthcare systems. The research provided in this thesis has through a mixed-method systematic approach focused on capacity management in a multihospital system consisting of several healthcare providers, including all types of healthcare personnel rather than only pools of nurses. We have confirmed previous findings in the literature but also developed new knowledge to help guide a more efficient capacity management in healthcare systems.

The research project has been focused on pooling capacity in terms of staff. However, other pool configurations have been identified in the literature, namely pooling of patients (Song et al., 2015) and pooling of equipment (Song et al., 2020). Other prerequisites and barriers might be found in other pool configurations. Moreover, the research has been focused on periods of time where normal circumstances are predominated and not periods of time where the system is put under shock or great pressure. The recent covid-19-pandemic have enforced efforts that are similar to a capacity pooling system, where employees have been reallocated to parts of the system where most needed, such as intensive care units. Hence, several interesting potential areas for future research have been identified to further increase knowledge on capacity pooling in healthcare systems, which will be presented and further discussed below.

## 6.2 Areas for future research

Four potential areas for future research have been identified in this research project: design possible capacity pooling configurations using real data, expand the capacity pooling concept to resource pooling and patient pooling, identify potential opportunities and barriers to capacity pools according to healthcare employees, and using digital solutions as a capacity pooling approach. These four areas will be further described and discussed below.

### 6.2.1 Design possible capacity pooling configurations using real data

In paper 1 appended in this thesis, a numerical example using fictious data was provided to describe how portfolio theory could be applied in a capacity pooling approach. As the data in the example was fictious, the example is most likely also a simplified version of reality. Different healthcare units experience different types of variations in capacity and demand due to the characteristics of the healthcare provided. For example, emergency departments with only acute care will have one type of pattern regarding patient arrival rate and length of stay, while primary care centers with a large amount of planned outpatient care will face a different type of challenge in their capacity planning process. Paper 2 investigates how different tools for short-term flexibility in healthcare capacity management are applied depending on these issues.

Service operations management is concerned with the alignment of capacity and demand, due to the simultaneous production and consumption of the service provided. Therefore, it would be of interest to conduct a more thorough analysis of different capacity pool configurations where the matching of capacity and demand in healthcare services is considered. The findings in paper 1 could be used as a basis for such analyses and the results in paper 2 could be used as a guideline for how different types of healthcare units could be matched in a capacity pool depending on the characteristics of the healthcare provided. Real data should be used in such a study, in order to capture issues that are rationalized in hypothetical examples but can emerge in real-life settings.

There are several potential benefits from performing a study where real data is used to develop a possible capacity pooling configuration. For example, possible issues could be discovered regarding the alignment of capacity and demand that have not been obtained in the theoretical analysis performed in paper 1. The complexity of capacity management in healthcare systems could be captured, where sometimes several types of resources must be available simultaneously to sufficiently meet the demand. Furthermore, a deeper understanding on the potential capacity utilization of an entire system where a capacity pooling approach is implemented could be obtained through such a study. Finally, conducting a study using real data would provide further validity to the findings in the research on capacity pooling in healthcare systems.

### 6.2.2 Expand the capacity pooling concept to resource pooling and patient pooling

Another interesting future research path on capacity pooling in healthcare system is to consider different types of pooling configurations. In this research project, a capacity pool has been limited to a pool consisting of healthcare staff such as physicians, nurses, and assistant nurses. In the literature there are other examples of pooling approaches in healthcare systems. Song et al (2020) analyze the effects of the pooling of beds at different hospital wards. This could be extended to other equipment or resources, such as magnetic resonance imaging scans or operating theatres, that are usually bottlenecks in the capacity planning process in healthcare systems. Moreover, Song et al (2015) analyze a patient pooling approach in an emergency department, where patients are pooled into the same queue instead of having separate queues to different physicians.

The three different pooling configurations; staff, equipment, and patient, are of interest since there are possible benefits to be achieved in capacity utilization for all three configurations separately. For example, pooling all patients to one single queue instead of separate queues will theoretically reduce the overall waiting times for patients. A combination of two or three pooling approaches could be even more beneficial in terms of capacity utilization. Therefore, a potential future research area is to extend the capacity pooling definition in healthcare systems to comprise staff, patient, and equipment pools combined. Potential barriers to such combinations of pooling approaches could be investigated, as well as potential benefits in terms of capacity utilization.

### 6.2.3 Identify potential opportunities and barriers of capacity pools according to healthcare employees

An interview study was conducted in the early phase of this research project, where department managers were asked questions regarding potential barriers to capacity pooling in healthcare systems. In order to validate the findings, and to obtain other points of view on the results, an interview study where the findings are discussed with healthcare employees could provide important information for the design and implementation of capacity pools.

The interviews could be conducted with either healthcare employees that have already acquired work experience from a capacity pool, or healthcare employees that are potential candidates for capacity pools in forthcoming implementations. The former types of interviews could provide new insights on, for example, the identified barriers to capacity pools and how staff experience the work in a capacity pool. It could either validate the findings that have been found in previous papers published within this research project, or provide new perspectives on healthcare employees' experiences of working in capacity pools that could be of value for future implementations. The latter types of interviews could result in, for example, knowledge on incentives for healthcare employees to be recruited to a capacity pool.

### 6.2.4 Using digital solutions as a capacity pooling approach

Finally, a potential area for future research that has been identified within this research project is to further analyze the use of digital solutions such as e-visits. KC et al. (2020) argue that digitalization and connected health is an interesting area for future research. This potential research area is of interest for two reasons.

Firstly, in paper 3, physical distance was identified as a barrier to a capacity pooling approach in healthcare systems, where digital solutions could be a tool to overcome this potential barrier. Such solutions could be used differently in different types of units; for example, in primary care centers or units with a larger amount of outpatient care, digital e-visits could be used as a substitute for physical visits. Pooling capacity in a healthcare system such as Region Västra Götaland would then result in that staff could be included in the same pool regardless of where in the region the staff is physically located. Moreover, digital solutions are often used in medical consultations between specialists. It could be investigated how these consultations could be extended to overcome potential barriers related to physical distance even in inpatient care.

Secondly, digital solutions could be a tool to a capacity pooling approach in itself. There are already examples of healthcare providers that use digital applications for primary care centers, both through public administration and private actors. It would be useful to investigate how digital solutions could be used as a capacity pooling approach where physical distance would no longer be regarded as a barrier, and both healthcare employees and patients could be geographically located anywhere in a healthcare system.

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